Theoretical and Experimental Evaluation of a Wavelength-stabilized Talbot Cavity with a Volume Bragg Grating

David Pabœuf, Gaëlle Lucas-Leclin, Nicolas Michel, Michel Krakowski, Patrick Georges

Theoretical and Experimental Evaluation of a Wavelength-stabilized Talbot Cavity with a Volume Bragg Grating

D. Paboeuf[1], G. Lucas-Leclin[1], N. Michel[2], M. Krakowski [2], P. Georges[1]

1. Laboratoire Charles Fabry de l'Institut d'Optique, CNRS, Univ Paris-Sud, Campus Polytechnique, RD128, 91127 Palaiseau – France
2. Alcatel-Thales III-V Lab, RD128, 91767 Palaiseau – France
david.paboeuf@institutoptique.fr

Abstract: We describe the coherent combining and the wavelength stabilization of 10 tapered lasers in an external Talbot cavity. The use of a volume Bragg grating as feedback element to narrow the spectrum is demonstrated.

1. Introduction

High power laser diode arrays are very attractive for applications such as solid-state laser pumping or laser material processing due to a very good overall efficiency. Inconveniently, however, the beam quality and the spectrum bandwidth are often too far from the requirements for demanding applications. A well-known way to enhance the beam quality of several lasers is to induce a coherent combining of the emitters by phase locking between the emitters. Moreover, volume Bragg gratings are extensively utilized for the narrowing and the stabilization of the spectrum of broad area lasers and arrays [1]. We propose to utilize the self-imaging Talbot effect inside an external cavity to coherently combine the emitters of an array of laser diodes, and thus to force them to operate in the in-phase supermode. With the aim to favor the coherent coupling and to strongly control the emission wavelength, we use a volume Bragg grating (VBG) as the external cavity mirror of the Talbot cavity.

In our experiments, the laser source is an array of 10 index-guided tapered lasers with a 100 µm-pitch emitting around 975 nm. The active layer consists of a strained GaInAs quantum well embedded in a large optical cavity. The lateral structure of the emitters is a tapered ridge with a narrow angle (< 1°) and an overall cavity length of 2.5 mm [2]. Finally the rear facet is high-reflection coated. A power of 4 W of free running emission have been obtained at 6 A. The far field full-width at $1/e^2$ in the slow axis is 2.7°.

2. Theoretical study

Our theoretical description of the diffractive coupling between emitters induced by the free-space propagation of light within the external cavity closely follows the one detailed in [3]. The interelement coupling coefficients κ_{pq} of emitter p with emitter q are evaluated as the overlap of the diffracted beam $E_p(z)$ at $z = 2\times L_{ext}$ and the original emission $E_q(0)$. The eigenmodes of the $\{\kappa_{pq}\}$ matrix are the N array supermodes of the external cavity. This evaluation takes into account the diffraction losses at the edge of the laser array. At $2\times L_{ext} = Z_T$, both the in-phase and out-of-phase modes are exactly self-imaged with identical coupling coefficients, which forbids any spatial discrimination between them. On the contrary, the discrepancy between these 2 modes is maximal for $2\times L_{ext} = Z_T/2$, which is thus preferred. Indeed, at that distance, the out-of-phase mode is self-imaged whereas the in-phase mode is imaged with a lateral shift of p/2. By angling the output mirror to $\lambda/2p$, the in-phase mode may then be selected.

The near-field of each emitter was fitted by a Gaussian profile with a waist w = 10 µm (half-width at $1/e^2$). The Fresnel diffraction integral of the field E(z) of the whole array at a distance z has then an analytical expression. We have computed the coupling efficiency of the supermodes of the cavity with and without tilting the external mirror (see fig 1). The tilt of the mirror was simply modelled as a linear phase shift. With no angle, the out-of-phase mode (j=10) has the highest coupling efficiency and should then be selected by the cavity. On the contrary, with a tilt of $\lambda/2p$, the in-phase mode (j=1) is favoured with a discrimination rate higher than 20 % with the next mode whereas the coupling efficiency of the out-of-phase mode is close to zero.

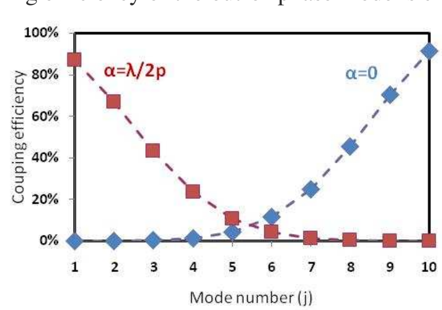

Fig. 1. Coupling efficiency of the supermodes of an array of ten emitters (w=10 µm, p=100 µm) for a $2\times L_{ext} = Z_T/2$ long cavity. (blue diamond- α=0, red square - α=λ/2p). The in-phase (respectively out-of-phase) mode is mode 1 (respectively. mode 10).

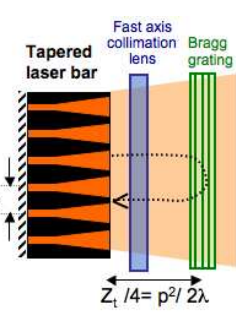

Fig. 2. External cavity set-up

Furthermore, we have evaluated the influence of a VBG as the external cavity reflector on the array modes. Taking into account the specific VBG reflectivity [4], we have computed the modified supermodes of the external cavity and their coupling efficiencies; no significant changes have been noticed as long as the array beam divergence remains lower than the angular acceptance of the grating. The major modification observed is a slight change of the self imaging distance due to the distributed reflection inside the grating.

3. Experiments

First experiments have been carried out with a plane R = 40% mirror as the external cavity, and two different tapered laser arrays: one (I-3) with a standard anti-reflection (AR) coating on the front facet (few %) and the second one (I-5) with a $R < 10^{-3}$ coating which prevents free running of the emitters without any external mirror. The beam from the laser array is collimated in the fast-axis direction with an acylindrical lens (f' = 1.46 mm). With a pitch of 100 µm, the Talbot distance is 20 mm and our external cavity length is thus L_{ext} = 5 mm (Fig. 2). With both arrays, coherent combining of the emitters has been observed in the far field profile (Fig. 3) on a large range of operating currents, the in-phase mode being easily favored by a slight mirror tilt. The angular width of each lobe is about 1 mrad, consistently with the theoretical model. The number of lobes results from the filling factor of the array, which is only 20%. We obtained a maximum output power of 550 mW at 3A with the I-3 and 300 mW at 2.3A with the I-5.

The degree of coherence η of the emitted beam is evaluated from the far-field profile; with the I-3 bar (standard AR coating) η is about 40% at threshold and decreases to 30 % at the maximum operating current. It is mainly limited by the self-operation of the emitters. On the contrary a good contrast in the far field (η = 50%) is obtained with the I-5 bar. This demonstrates that good AR coatings are crucial for efficient external cavity operation. Finally, the spectrally-resolved near-field reveals that even if the external cavity ensures a stabilization of the wavelength of each emitter within 0.3 nm (spectrum analyzer limited) near the laser threshold, the overall spectrum is strongly enlarged over 5 nm at higher operating current.

In order to narrow and stabilize the spectrum, we used a VBG as the external cavity mirror of the previous Talbot cavity. Our 0.7-mm-thick grating has a maximum reflectivity of 40% at 976 nm and an angular acceptance of 2° (full width at $1/e^2$). As previously, coherent operation of the in-phase mode has been observed with a degree of coherence around 50% on the whole operating range with the I-5 bar. The spectrally-resolved near-field shows that each emitter is locked to the Bragg wavelength with no parasitic peak (Fig. 4), and remains stable whatever the operating current. The spectral bandwidth is reduced to less than 300 pm. We obtained an output power of 220 mW at 2.3.

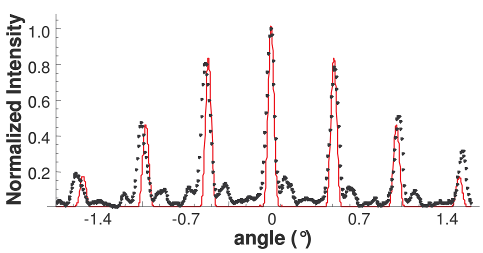

Fig. 3. Far field profile at I=2.7A (P=500mW). (black dots – measured far field, red line – theoretical far field)

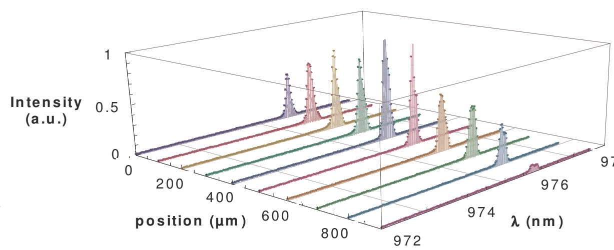

Fig. 4. Spectrally resolved near-field in the cavity with a VBG (I=1.9A, P=200 mW)

4. Conclusion

We have demonstrated the efficient coherent combining of an array of 10 tapered lasers in a Talbot external cavity. Wavelength stabilization has been achieved simultaneously by use of a volume Bragg grating as the external mirror. In this simple and compact set-up a degree of coherence around 50% is obtained with a narrow and stable spectrum. These results are very promising for the realization of a compact high brightness laser source. Further increase of the output power is expected from a better thermal management of the set-up and a lower grating reflectivity. Simulations will be carried on by taking into account the propagation inside the amplifier medium.

Acknowledgments: This work was supported within the European project BRIGHTER.EU under grant referenced FP6-IST-035266. The authors acknowledge J.P. Huignard (Thales RT) for fruitful discussions. D. Paboeuf thanks the French Army (Délégation Générale de l'Armement) for funding his PhD.

References

[1] B. L. Volodin *et al.*, "Wavelength stabilization and spectrum narrowing of high-power multimode laser diodes and arrays by use of volume Bragg gratings," Opt. Lett. **29**, 1891-1893 (2004)

[2] M. Krakowski *et al.*, "1 W high brightness index guided tapered laser at 980 nm using Al-free active region materials," Electron. Lett. **39,** 1122–1123 (2003).

[3] D. Mehuys *et al.*, "Modal analysis of linear Talbot-cavity semiconductor lasers", Opt. Lett.,**16**, 823-825 (1991)

[4] H. Kögelnik, "Coupled wave theory for thick hologram gratings", Bell. Syst. Tech. J. **48**, 2909-2947